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Abstract

Some studies have reported a low rate of False Recognition (FR) in individuals with Autism Spectrum Disorder (ASD) relative to non-autistic comparison participants. This finding however, has not always been replicated and the source of the discrepancy remains unknown. We hypothesised that poor episodic memory functions may account for this finding. We used an adapted version of the DRM paradigm which presents lists of Words, Pictures or Word-Picture Pairs to obtain measures of performance which reflect episodic (Hits and False Alarms - FA) and semantic (FR) memory functions. Results showed a decreased rate of FR in ASD individuals with lists of Words which rose above the rate seen in non-autistic comparison participants with lists of Word-Picture pairs. This increased rate of FR in ASD was accompanied by a parallel increase in Hits and a decrease in FA which reached a similar level in the two groups. Poor episodic memory functions may prevent individuals with ASD from acquiring item information which in turn precludes the formation of semantic links between items. This could render them less prone to FR.

Key words: False Recognition; Autism Spectrum Disorder; DRM paradigm; Gist Memory

Introduction

Gist-based illusions refer to the experience of falsely remembering items from categorical clusters which were not sourced at the time of encoding (Roediger & McDermott, 1995). These memory illusions, also known as false memories (i.e., false recognition or false recall), have been investigated in individuals with Autism Spectrum Disorder (ASD). The results from previous studies remain controversial. Some authors have reported reduced false memories in individuals with ASD relative to non-autistic comparison participants (e.g., Beversdorf et al. 2000), whereas others have found no differences between these groups (e.g., Bowler et al., 2000a). The source of this discrepancy is not well understood. The available literature suggests a heterogeneous impact of ASD on declarative memory (Bennetto et al. 1996; Boucher et al., 2012). In the present study we addressed the hypothesis that episodic memory impairments may account for reduced false memories in ASD. Below we review the evidence supporting this hypothesis.

Using a version of the Deese, Roediger and McDermott (DRM) paradigm (lists of words), Beversdorf et al. (2000) observed that individuals with ASD were less likely than non-autistic comparison participants to falsely recognise non-studied words which were semantically related to previously studied words (i.e., critical lures). The authors interpreted this reduced rate of false recognition (FR) as a limited ability of individuals with ASD to use context specific information to link exemplars of a common semantic category, which is thought to reflect impaired gisting abilities (Beversdorf et al., 2000; Beversdorf et al., 2007; Bowler et al., 2008; Kamio & Toichi, 2007; McCleery et al., 2010). However, Bowler et al. (2000a) used a procedure similar to that described by Beversdorf et al. (2000) and found no evidence of reduced FR in individuals with Asperger's syndrome. Failures to replicate the finding of reduced FR in individuals with ASD have also been reported by Gaigg & Bowler

(2009) using emotionally charged words and by Molesworth et al. (2005) using prototypes of visual stimuli. Therefore, there may be factors other than limited gisting abilities which underlie the decreased rate of FR previously reported.

For example, in Beversdorf et al. (2000)'s study, ASD individuals showed a patten of performance on the false memory test compatible with episodic memory impairments. Relative to non-autistic participants ASD individuals produced more "yes" responses when they were asked whether they had heard either studied items or non-studied items which were distantly related to the studied items. However, they produced fewer "no" responses than non-autistic subjects for both word categories, indicating some form of response bias. This poor discrimination between studied and non-studied words resulted in an increase in false alarm rates and may be consistent with an episodic memory impairment. However the group were unimpaired on other episodic memory tasks including the CVLT although these results may have been affected by limited power. A closer inspectition of their data reveals a medium effect size for this test (Cohen-*d* = 0.45, r = 0.22) and a rather large effect size when "no" reponses to previously presented items (i.e., misses) were compared across groups (Cohen-*d* = 0.91, r = 0.41, see also "no" responses to related items). Individuals with ASD may have forgotten more items than controls and this may have prevented them from accumulating information necessary to identify the presence of categorical clusters, the building blocks of false memories. This would reflect episodic rather than semantic memory impairments.

Individuals with ASD typically present with episodic memory deficits (Bowler et al., 2010; Gaigg & Bowler, 2008; Toichi & Kamio, 2003; Williams et al., 2006). Bowler et al. (2000b), have reported that the episodic memory impairments in ASD could be attributed to failures in quantitative aspects of memory. They found that recognition in individuals with Asperger's syndrome was associated with less remembering and more knowing reponses,

suggesting that whereas active recollection of information from episodic memory memory is impaired, less demananding familiarity processes may remain preserved. This proposal was further supported by Bowler et al. (2007). Gaigg, et al. (2014) have recently reported memory impairments in adults with ASD when they remembered a random sequence of names of famous historical figures but not when they remembered these names according to their chronological order in history. The authors claimed that this dissociation supports a preserved semantic and an impaired episodic memory system in ASD. Fruthermore, recent studies have suggested that impaired associative memory functions may also be a mechanism underlying poor episodic memory functions in ASD (Bowler et al., 2014; Gaigg et al. 2008).

In order to correctly associate category-specific items in a way that leads to activation of semantic clusters, as it occurs with the DRM paradigm, one needs to retain a number of items sufficient to realise the common semantic thread (e.g. see Haarmann et al., 2005; Nissan et al., 2013). Using a learning procedure, Bennetto et al. (1996) found that autistic children performed more poorly than non-ASD children throughout the learning trials and produced more false recognitions in delayed memory. Hence, the hypothesis that reduced memory illusions in individuals with ASD may be a by-product of poor episodic memory functions is one worth investigating. To this aim, it is also important to understand the type of stimuli with which individuals with ASD are more likely to show reduced FR. Available studies reporting reduced FR in ASD have commonly used verbal stimuli (Beversdorf et al., 2000; 2007). ASD individuals present with developmental delay of language functions (Kamio et al., 2007). Hence, gisting impairments in ASD in the verbal domain could originate from poor language abilities, difficulties in binding items within semantic categories or from a combination of these factors (Kamio et al., 2007; Kamio & Toichi, 2007; Toichi & Kamio, 2003). It has been proposed that the rich perceptual details of visual stimuli during pictorial encoding can help participants to evoke more detailed recollection processes which

would support recognition (i.e., the 'distinctiveness heuristic' hypothesis, see Schacter et al., 1999). Thus the use of pictorial stimuli may lead to greater FR in ASD individuals by augmenting their episodic memory.

Using a word completion task with lists of prime/target pairs which could be word-word or picture-word pairs, Kamio and Toichi (2000) reported that high-functioning adolescents and adults with autism performed significantly better than controls on the picture-word task than on the word-word task. They suggested a possible advantage of pictures over words in accessing semantics in autism (see also McCleery et al., 2010). Hillier et al. (2007) assessed word and visual recognition in ASD individuals. They replicated the findings of Bowler et al. (2000a) using word recognition but observed reduced FR using visual arrays of canonical shapes in colour. The authors acknowledged that the limited semantic meaning of their visual stimuli may have been the crucial factor. They suggested that meaningfulness may make associations between stimuli more robust and therefore increase susceptibility to illusory recognition among those with ASD.

The evidence reviewed above suggests that there does not appear to be an obvious factor (e.g., participant characteristics, experimental materials or task design) that could account for the discrepancies in these studies. However, episodic memory appears to play a role and may be affected by the modality of to be remembered stimuli (i.e., visual or verbal) as well as by meaningfulness. It is therefore important to furnish the literature with further evidence from studies that systematically compare the susceptibility of individuals with and without ASD to FR across various conditions which capture the factors reviewed here.

The present study

The main aim of the present study was to investigate episodic and semantic memory processes in individuals with ASD by comparing performance on Word, Picture or Word-

Picture versions of the DRM semantic priming paradigm (Roediger & McDermott, 1995). A word completion task was devised which assessed within-modality (Words or Pictures) and across-modality (Word-Picture) presentation of semantically related or unrelated stimuli. If the reduced gist-based memory illusions observed in individuals with ASD is due to a limited ability to identify the semantic thread within lists of items, and if this deficit is over and above their episodic memory impairment, the effect should be observed either with lists of words or with list of pictures. If, on the other hand, reduced gist-based memory illusions in ASD are primarily the result of episodic difficulties that attenuate memory for the list items that form the building blocks of the semantic thread, then conditions that boost episodic memory should lead to increases in memory illusions in ASD. Presenting words and pictures simultaneously should have such an effect as such dual presentation of information grants access to a more defined memory representation of each item. This should facilitate the identification of semantic links and should bring ASD individuals' performance to a level similar of that observed in individuals without ASD.

Our logic follows the proposal by Cann et al. (2011) about how gist extraction might proceed in the DRM paradigm. The presentation of lists of words would produce the encoding of a surface representation (i.e., verbatim trace), which activates neighbour engrams (i.e., simulations) for each list item on the basis of situational knowledge and other semantic relations. Because surface and gist processing occur in parallel, gist extraction would result from integrating both the experienced items and the individual simulations that are active at the time of encoding into a background situation, and this background situation represents the gist of the encoded episodic experience. Therefore, FR would emerge as the reactivation of a previously encoded episodic experience. Our proposal is that to build such a background situation, one needs to accrue enough information to facilitate the grouping of verbatim and simulated traces into gist representations. We therefore predict that ASD individuals would

benefit from the contextual information provided by Word-Picture pairs as this cross-modal information would grant wider access to both episodic and semantic representations. This benefit would reflect in an increase in their FR.

Methods

Participants

Participants were recruited from the Foundation "Integrar" of Medellin, Colombia. Fifteen adolescents with ASD (10 female) and fifteen Comparison participants (6 female; $\chi^2 = 2.14$, ns) were recruited into the study using an opportunity sampling procedure. Comparison participants were relative of members of the staff or common visitors to the Foundation. All the participants are all well known to the Foundation's staff as they take part in regular health and educational activities which involve their family and the community. The fact that ASD and comparison participants came from a similar environment and background is an advantageous feature of this sample. All the participants and/or their parents gave their written consent prior participation. The study was reviewed and approved by the Psychology Research Ethics Committee, University of Edinburgh. ASD was diagnosed according to the criteria set by the DSM-IV-TR. Groups were matched for age (Comparison participants: M = 18.53, SD = 5.29; ASD: M= 16.13, SD = 4.13; $t = 1.38$, p = 0.177) and years of education (Comparison participants: M = 11.08, SD = 3.23; ASD: M = 8.72, SD = 3.16; $t = 1.76$, p = 0.092).

Assessment tools

Functional scales

The Autistic Spectrum Inventory (ASI; Rivière, 2004) measures the magnitude and severity of the autistic traits and informs on the functional level. The scale comprises twelve

dimensions: (1) Social relationships, (2) ability to engage in shared activities, (3) subjective interactions (e.g., Theory of Mind), (4) communication, (5) expressive and (6) receptive language, (7) anticipation, (8) flexibility, (9) awareness of ongoing actions, (10) fiction and imagination, (11) imitation and (12) suspension. Each dimension score ranges from 0 and 8 with higher scores indicating greater impairment. A total score is computed by adding the sub-scores of the domains above into four dimensions (Social Relations: 1-3, Communication and Language: 4-6, Anticipation and Flexibility: 7-9, and Symbolization: 10-12). Scores from 0-1 fall outside ASD, above 2 indicate mild ASD, above 4 indicate moderate and 8 and above indicate severe ASD. The minimal total score suggestive of mild ASD is 24. We also used the Inventory for Client and Agency Planning - ICAP (Bruininks et al., 1986). The inventory assesses adaptive behaviour and skills in areas such as motor, social communication, activities of everyday life and in the community. Impairments in these areas are identified by computing the discrepancy between the actual and the age adjusted score. Domain difference scores from -5 to +5 and from +6 to +10 indicate average and high average functioning level respectively. These scales permit a more thorough assessment of how the individual's functional level may contribute to adaptive behaviour than a simple IQ score.

FR task

Three sets of materials were created (see Supplementary Table 1). The first were twelve Spanish word lists derived from Fernandez et al., (2006) word association norms. We chose concrete nouns as words which were subsequently converted to pictures. The second set of stimuli consisted of pictures matching the representations of the chosen words. The pictures were taken from the stock photo program "Mammoth 800 Thousand Clipart Version 3.2.0.1, 2004". We checked for consistency with native Spanish speakers and Native Colombian-Spanish speakers ensuring that the words matched the picture for the to-be-assessed

population. The third set consisted of words and pictures together (see Figure 1.A for examples of these materials). The task consisted of three conditions: Words, Pictures, and Word-Pictures pairs (Figure 1.A). Each condition has a critical item which was not presented during the study phase and fifteen studied items.

Figure 1 A & B about here

Twelve lists were constructed for each condition and presented in a random order. Between each list, participants carried out simple mathematical problems for 30 seconds, which acted as a distracter task. After studying 12 lists, participants moved on to the recognition phase. They saw the 12 critical lures which were not present in the study lists, 24 studied items related to the critical lures and 12 non-studied unrelated items (see Fig2.A and Supplementary Table 1 for the whole set of stimuli in Spanish). They were instructed to respond using two keys previously assigned from the computer keyboard. The sequence of the task is shown in Figure 1.B. The procedures for each condition were identical. Participants were told that they were taking part in a memory experiment presented on a computer. Participants were instructed as follow: ***Encoding****: In the first part of the task you will be presented with sequences of [words, pictures, word-pictures pairs]. After each sequence of [words, pictures, word-pictures pairs], you will be asked to solve some simple mathematical problems. There will be a number of sequences in this task. Please, study the [words, pictures, word-pictures pairs] carefully and respond to the math questions as accurately as you can. Press any key to start the task when you are ready.* ***Recognition:*** *This is the second part of the task. You will see a sequence of [words, pictures, word-pictures*

pairs] which will be briefly presented. Some of these [words, pictures, word-pictures pairs] were presented in the first part of the task and others are new. Your task is to decide whether these [words, pictures, word-pictures pairs] were presented in the first part or not. You will press the key labelled "Yes" if the [words, pictures, word-pictures pairs] were presented in the first part of the task or the key labelled "No" if they were not. Press any key to start the task when you are ready. The order of presentation of the experimental condition was counterbalanced across participants. Participants performed each condition with an interval between them of 2 weeks. This was added to eliminate memory traces of the studied materials.

Analysis

We calculated the percentage of Hits (Hits = Yes responses to studied items), False Alarms (FA = Yes responses to non-studied unrelated items), and False Recognition (FR = Yes responses to non-studied related items) in the three experimental conditions (Word Only, Picture Only and Words-Picture pairs) for the two groups. We first compared these dependent variables across the two groups using independent sample *t*-tests. For each contrast we report on the statistics (*t*), the significance value (p) and the effect size (Cohen-*d*: 0.2 small, 0.5 medium and 0.8 large). To assess whether episodic and semantic memory differentially contributed to task performance in the two groups across the three experimental conditions we conducted a 3-way ANOVA with Group (Comparison participants vs. ASD) as the between-subjects factor and Condition (Word Only vs. Picture Only vs. Word-Picture Pairs) and False Memory (FA vs. FR) as the within-subjects factors. We report on the statistics (*F*), the significance value (p), the effect size (η^2: 0.1 small, 0.24 medium and 0.31 large) and power (β). In the context of the DRM paradigm, the FA rate would reflect the strength of episodic memory whereas FR would reflect the strength of semantic memory. We predict that

individuals with ASD would experience lower FR under conditions in which their episodic memory difficulties were evident (i.e., low Hit rate and increased FA rate), because under such conditions the 'gisting' that drives FR is attenuated. To assess this hypothesis we performed correlations between Hits and FR.

Results

All the individuals with ASD recruited into the study showed mild to moderate ASD traits compatible with a high functional level as assessed by the ASI [Social Relations: 6.15 (0.6), Communication and Language: 6.23 (0.8), Anticipation and Flexibility: 6.38 (1.0), and Symbolization: 6.46 (1.1), Total Score: 25.23 (3.03)]. They also showed a high level of independence according to ICAP's domains [Motor Skills: M = 7.75, SD = 2.99; Social & Communication Skills: M = 9.64, SD = 4.76; Personal Life Skills: M = 10.47, SD = 3.8; Skills within the Community: M = 9.79, SD = 3.68; General Independence Index: M = 9.47, SD = 3.8] (see reference values above).

Mean data from the adapted DRM paradigm are shown in Table 1. The results showed that individuals with ASD tended to miss more studied words and falsely recognise more non-studied unrelated items (i.e., FA) than comparison participants (with a medium effect size). A similar increase in FA was observed for Pictures only. However, such an effect disappeared when Word-Picture pairs were presented. For critical lures, individuals with ASD generated a lower FR rate than comparison participants for Word only. However, when Pictures alone or Word-Picture pairs were presented, ASD individuals' FR increased above the level seen in Comparison participants. These results suggest that our ASD individuals did present with episodic memory impairments associated with reduced FR, and that these impairments differed across the experimental conditions.

Table 1 about here

The three-way ANOVA (Group: Comparison participants vs. ASD x Condition: Word Only vs. Picture Only vs. Word-Picture Pairs x False Memory: FA vs. FR) revealed no effect of Group [$F(1,28) = 2.1$, p = ns , $\eta^2 = 0.26$, $\beta = 0.29$]. The effect of Condition was significant [$F(2,56) = 32.14$, $p < 0.001$, $\eta^2 = 0.73$, $\beta = 1.0$] whereby False Memory followed the pattern Word Only > (Picture Only = Word-Picture Pairs) ($p<0.001$). The effect of False Memory was also significant [$F(1,28) = 109.60$, $p < 0.001$, $\eta^2 = 0.89$, $\beta = 1.0$] whereby the rate of FR was greater than that of FA. Critically, the 3-way interaction was found to be significant [$F(2,56) = 12.22$, $p < 0.001$, $\eta^2 = 0.55$, $\beta = 0.99$].

Post-hoc tests carried out across Group for each Condition separately (independent-sample *t*-tests) showed (Table 1) that in the Word Only condition, ASD individuals showed a marginal increase of FA relative to comparison participants, and a significant decrease in FR. The Picture Only condition brought FR in ASD individuals to a level above that seen in the Comparison participants. However, episodic memory did not improve in the former group as suggested by a significant increase in FA. In the Word-Picture Condition ASD individuals and the comparison group did not show significant differences in any of the contrasts performed. Post-hoc tests carried out across Condition for each Group separately (paired-sample *t*-tests) showed that in Comparison participants the Word Only condition led to significantly more FA that the Picture Only [$t(14) = 3.63$, $p <0.05$, $d = 0.74$] and Word-Picture Pairs condition [$t(14) = 2.96$, $p <0.05$, $d = 0.54$]. The FA rate in the Picture Only was significantly smaller than in the Word-Picture Pairs condition [$t(14) = 2.28$, $p <0.05$, $d = 0.17$] but only with a small effect size. The analysis of FR in the comparison group showed

that significantly more illusory memories were produced during the Word Only condition than in the Picture Only [$t(14) = 6.8$, $p < 0.001$, $d = 1.89$] and in the Word-Picture condition [$t(14) = 7.43$, $p < 0.001$, $d = 1.74$]. FR in the Picture Only condition and in the Word-Picture pairs condition did not differ in comparison participants [$t(14) = 0.54$, p = n.s., $d = 0.12$]. In ASD individuals the only contrast that showed a significant effect was that between FA in the Word Only condition and in the Word-Picture Pairs condition [$t(14) = 3.85$, $p < 0.05$, $d = 1.46$].

In sum, the results from the 3-way ANOVA suggest that there was a decrease in the rate of FA and FR in comparison participants from Word Only to Picture Only, and from Picture Only to Word-Picture Pairs. In ASD individuals however, FA also decreased in the same fashion but FR showed the opposite pattern, thus supporting the proposal that as the strength of episodic memory increases in ASD individuals so does their gisting ability, leading to a higher rate of illusory memories.

Finally to further investigate the relationship between episodic and semantic memory as a potential account for the reduced rate of FR in ASD during the DRM paradigm we performed correlation analyses between Hits and FR. A correlation between these variables was observed only in the Word Only condition which was marginal for Comparison participants ($r=0.504$, $p=0.055$) but significant for ASD individuals ($r=0.71$, $p =0.003$).

Discussion

We investigated the hypothesis that presenting items in two different modalities in the DRM paradigm would differentially affect the degree of processing of contextual and semantic information and consequently alter ASD individuals' performance. The assumption was that if the reduced FR observed in ASD individuals was primarily due to a limited ability to

identify the semantic thread within list of single items, this deficit should be stimulus-independent. We predicted that Word-Picture pair would grant access to a more precise memory description of each item. This in turn would facilitate both the retention of information and the identification of semantic links that would bring ASD individuals' performance to a level similar to that observed in non-autistic individuals. The results of the present study confirmed such a hypothesis and shed new light into the potential sources of discrepancy in earlier studies.

We observed reduced FR in ASD individuals for Words only (see also Beversdorf et al., 2000; 2007). We also confirmed that ASD individuals presented with difficulties in processing words in episodic memory. Poor item-specific memory has been found to be associated with reduced FR in individuals with autism (Bennetto et al., 1996) and in amnesics (Nissan et al., 2013). For example, Bennetto et al. (1996) assessed delayed recognition and found that autistic individuals produced more false positive responses for the shared category and semantic similar items than comparison participants. Autistics showed difficulties during the learning trials, suggesting limitations in clustering items within semantic categories. However, after learning the items, their gisting abilities were revealed. This view fits with the data from an amnesic patient recently assessed by Nissan et al. (2013) also using the DRM paradigm. They found that the amnesic patient's FR significantly increased from the standard version of the task to a version in which learning to criterion was required. In fact the amnesic patient's FR did not differ from that of comparison participants in the criterion task. The authors argued that amnesics could gist once their item memory improved (see also Ciaramelli et al., 2006). In our hypotheses, we predicted that poor episodic memory in ASD individuals would not allow the retention of sufficient items. The few retained items would be scattered in memory obscuring any semantic link between them. Increases in episodic

memory would lead to more accumulation of item information enabling semantic categories to be distinguished.

Our results are consistent with this hypothesis. Presenting Word-Pictures pairs brought ASD individuals' FR to a level similar to that seen in Comparison participants. Hillier et al. (2007) found reduced FR in ASD individuals using visual stimuli. However, Hillier et al. (2007) used meaningless coloured shapes (i.e., Square, Circle, Oval, etc.) whereas here highly familiar objects were used (Figure 2.A). The memoranda in these two studies were qualitatively different as common objects have stronger representations in long-term memory. However, it is worth noting that the increased rate of FR observed in the ASD group during the Picture Only condition does not seem to reflect improved episodic memory functions. This group showed a significantly higher rate of FA during this condition. Meaningful pictures alone may trigger familiarity-based processes which may bias the responses towards the option "old" (Roediger, McDermott, & Robinson, 1998). Hence, the increased rate of FR cannot be reliably interpreted as an improvement of gisting abilities but rather as an increased response bias in the presence of an impaired episodic memory system.

This problem was overcome when Word-Picture pairs were presented, perhaps encouraging more context-rich recollection processes which became available after boosting episodic memory functions. Should the reduced FR observed in ASD individuals when only Words were presented be primarily due to poor gisting abilities, this increase should not be observed. Hence, these results raise the question of which memory processes are these cross-modal stimuli influencing, semantic, episodic or both.

Episodic memory seems to facilitate semantic retrieval by providing organizational strategies or efficient route of access (Greenberg et al., 2009; see also Bennetto et al. 1996 for evidence from children with ASD using the CVLT children's version and Cann et al., 2011 for similar suggestions in the DRM paradigm). Ciaramelli et al. (2006) introduced a

manipulation to the DRM paradigm which was aimed at enhancing memory for studied words (episodic memory) and which led to improved gisting abilities (semantic memory) in amnesics. In the present study we have found that poor episodic memory underpins gisting impairment in ASD and that this accounts for reduced FR. The results from the correlation analyses showed that FR in ASD is attenuated in conditions in which the number of Hits is also attenuated. However, as the strength of their episodic memory increased, the dependency of semantic memory (e.g., FR) on episodic memory (e.g., Hits) decreased and the two systems ceased to show associations.

Our results may also be interpreted on the basis of the assumptions laid out in the 'Task Support Hypothesis' (Bowler et al., 1997). According to this hypothesis, procedures that provide cues to remember stimuli at test attenuate the memory difficulties experienced by individuals with ASD. In our task, presenting each item using cross-modal information may have created opportunities for ASD subjects to enrich the contextual experience increasing by this means their distinctiveness in memory. As the identity of each item becomes clearer so does their semantic relation (see Supplementary Figure 2 for a Signal Detection Theory approach to our data). In a more recent study, Bowler et al. (2008) suggest that contrary to accepted wisdom, some memory processes in ASD might not be impaired but they may just require triggers (e.g., environmental signals) different to those required by non-autistic individuals. Our results support this assertion as the ASD individuals assessed in our study produced more FR for Word-Picture pairs than Comparison participants albeit the opposite pattern was observed with Words only.

An alternative but related account would be that ASD individuals' relational memory abilities are impaired (see Roediger, McDermott, & Robinson, 1998). This has been recently demonstrated in the context of word learning (Bowler et al., 2008), and in the context of feature binding (Bowler et al., 2014). The notion that such a memory function is necessary to

perform the task used in our study is not entirely new. Hunt and Einstein (1981) previously demonstrated that simultaneously encoding item-based and category-based information during word list learning enhances both memory for such lists and clustering abilities. Using a paradigm that is informed by Hunt and Einstein (1981), Gaigg, Gardiner and Bowler (2008) maintained that the relational memory impairment observed in ASD individuals may be the result of atypical use of contextual or environmental cues. Hence, the "Task Support Hypothesis" and the relational memory account may share cognitive underpinnings. In the context of our study we may argue that presenting pictures and words together may have facilitated the encoding of item identity and the accumulation of information in episodic memory. Such facilitation seemingly led to better access to memory routes that connect the items to supraordinate categories.

The ratio of FR between Comparison participants and ASD individuals showed an inverted pattern from Word Only to Word-Picture Pairs (Word Only: 1.4, Word Picture Pairs: 0.7). However, FA tended to get closer in the two groups (Word Only: 0.6, Word Picture Pairs: 0.9). FR may be a by-product of the interaction between episodic and semantic memory (see Table 1, see also Supplementary Figure 2). That is, when the strength of both episodic and semantic memory increases, items can be better remembered and they can also be better grouped into categories. This would lead to fewer false alarms and an increase in hit responses (see results from correlation analysis). Word-Picture pairs may have facilitated episodic memory to a level which allowed ASD individuals to realise the common semantic links (due to greater item-information accumulation). However, this may not have been sufficient to allow them to filter unstudied items. In a previous study which also used an adapted version of the DRM to assess healthy individuals and confabulating and non-confabulating amnesics (Ciaramelli et al., 2006), the authors reported a similar pattern of results (i.e., FR decreased in controls and increased in amnesics). They argued that

monitoring deficits would prevent confabulators from using increased episodic memory to counteract gist-based false memory, thereby showing increased FR to critical lures. Their interpretation is that confabulators are unable to benefit from enhanced gist-memory to reduce FR just because they have difficulties suppressing irrelevant materials. Control participants however, could take advantage of the enhanced gist-memory and suppressed FR. Taken together, these findings reinforce the view that the primary deficit in ASD may lie in episodic rather than in semantic functions.

Some limitations of the present study should be noted. First, the male/female distribution of the ASD sample in our study is not representative of the general ASD population (Newschaffer et al., 2007). ASD individuals were recruited into the study using an opportunity sampling procedure whereby all the children attending the Foundation were offered the opportunity to participate. Nevertheless, this may limit the generalizability of our findings and may call for more research into possible gender differences in ASD. Second, although the scales used to assess functional level in ASD have proved reliable in Spanish speaking countries, they are not the standard tools classically reported in the wider literature. However, a challenge psychologists from developing countries have long faced, is the use and interpretation of scales that were developed to assess populations which different cultural and social backgrounds (Grantham-McGregor et al., 2007; Peña, 2007).

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References

Bennetto, L., Pennington, B. F., & Rogers, S. J. (1996). Intact and impaired memory functions in autism. *Child Development*, 6, 1816-35.

http://dx.doi.org/10.2307/1131734

Beversdorf, D. Q., Narayanan, A., Hillier, A., & Hughes, J. D. (2007). Network model of decreased context utilization in autism spectrum disorder. *Journal of Autism and Developmental Disorders*, 37, 1040-1048.

http://dx.doi.org/10.1007/s10803-006-0242-7

PMid:17191098

Beversdorf, D. Q., Smith, B. W., Crucian, G. P., Anderson, J. M., Keillor, J. M., Barrett, A. M. et al. (2000). Increased discrimination of "false memories" in autism spectrum disorder. *Proceedings of the National Academy of Sciences of the United States of America*, 97, 8734-8737.

http://dx.doi.org/10.1073/pnas.97.15.8734

PMid:10900024 PMCid:PMC27017

Boucher, J., Mayes, A., & Bigham, S. (2012). Memory in autistic spectrum disorder. *Psychological Bulletin*, 138, 458-496.

doi: 10.1037/a0026869

Bowler, D. M., Gardiner, J. M., Grice, S., & Saavalainen, P. (2000a). Memory illusions: false recall and recognition in adults with Asperger's syndrome. *Journal of Abnormal Psychology*, 109, 663-672.

Retrieved from PM:11195990

Bowler, D. M., Gardiner, J. M., & Grice, S. J. (2000b). Episodic memory and remembering in adults with Asperger syndrome. *Journal of Autism and Developmental Disorders*, 30, 295-304.

Retrieved from PM:11039856

Bowler, D. M., Gardiner, J. M., & Gaigg, S. B. (2007). Factors affecting conscious awareness in the recollective experience of adults with Asperger's syndrome. *Consciousness and Cognition*, 16, 124-143.

doi:S1053-8100(05)00158-3 [pii];10.1016/j.concog.2005.12.001 [doi].

Retrieved from PM:16503169

Bowler, D. M., Matthews, N. J., & Gardiner, J. M. (1997). Asperger's syndrome and memory: similarity to autism but not amnesia. *Neuropsychologia*, 35, 65-70.

http://dx.doi.org/10.1016/S0028-3932(96)00054-1

Bowler, D. M., Gaigg, S. B., & Gardiner, J. M. (2008). Effects of related and unrelated context on recall and recognition by adults with high-functioning autism spectrum disorder. *Neuropsychologia,* 46, 993-999.

http://dx.doi.org/10.1016/j.neuropsychologia.2007.12.004

PMid:18243253

Bowler, D. M., Gaigg, S. B., & Gardiner, J. M. (2010). Multiple list learning in adults with autism spectrum disorder: parallels with frontal lobe damage or further evidence of diminished relational processing? *Journal of Autism and Developmental Disorders*, 40, 179-187.

http://dx.doi.org/10.1007/s10803-009-0845-x

PMid:19680798 PMCid:PMC2810365

Bowler, D. M., Gaigg, S. B., & Gardiner, J. M. (2014). Binding of Multiple Features in Memory by High-Functioning Adults with Autism Spectrum Disorder. *Journal of Autism and Developmental Disorders*.

doi:10.1007/s10803-014-2105-y [doi].

Retrieved from PM:24696375

Bruininks, R. A., Hill, B. K., Weatherman, R. F., & Woodcock, R. W. (1986). Inventory for Client and Agency Planning, ICAP. Riverside: DLM Teaching Resources.

PMid:3527719

Cann, D. R., McRae, K., & Katz, A. N. (2011). False recall in the Deese-Roediger-McDermott paradigm: The roles of gist and associative strength. *Quarterly Journal of Experimental Psychology*, 64, 1515-1542.

http://dx.doi.org/10.1080/17470218.2011.560272

PMid:21506047 PMCid:PMC3226830

Ciaramelli, E., Ghetti, S., Frattarelli, M., & Ladavas, E. (2006). When true memory availability promotes false memory: evidence from confabulating patients. *Neuropsychologia,* 44, 1866-77.

http://dx.doi.org/10.1016/j.neuropsychologia.2006.02.008

PMid:16580028

Fernandez, A., Diez, E., & Alonso, M. A. (2006). Normas de asociación libre en castellano. Grupo de Investigación en Memoria y Cognición. Available On-line: http://www.usal.es/gimc

Gaigg, S. B. & Bowler, D. M. (2008). Free recall and forgetting of emotionally arousing words in autism spectrum disorder. *Neuropsychologia*, 46, 2336-2343.

http://dx.doi.org/10.1016/j.neuropsychologia.2008.03.008

PMid:18440037

Gaigg, S. B., Gardiner, J. M., & Bowler, D. M. (2008). Free recall in autism spectrum disorder: the role of relational and item-specific encoding. *Neuropsychologia*, 46, 983-992. doi:S0028-3932(07)00389-2 [pii];10.1016/j.neuropsychologia.2007.11.011 [doi].
Retrieved from PM:18164320

Gaigg, S. B. & Bowler, D. M. (2009). Illusory memories of emotionally charged words in autism spectrum disorder: further evidence for atypical emotion processing outside the social domain. *Journal of Autism and Developmental Disorders,* 39, 1031-1038.
http://dx.doi.org/10.1007/s10803-009-0710-y
PMid:19296212

Gaigg, S. B., Bowler, D. M., & Gardiner, J. M. (2014). Episodic but not semantic order memory difficulties in autism spectrum disorder: evidence from the Historical Figures Task. *Memory*, 22, 669-678.
doi:10.1080/09658211.2013.811256 [doi].
PM:23815188

Grantham-McGregor, S., Cheung, Y. B., Cueto, S., Glewwe, P., Richter, L., & Strupp, B. (2007). Developmental potential in the first 5 years for children in developing countries. Lancet, 369(9555), 60-70.
doi:S0140-6736(07)60032-4 [pii];10.1016/S0140-6736(07)60032-4 [doi].
PM:17208643

Gras-Vincendon, A., Bursztejn, C., & Danion, J. M. (2008). Functioning of memory in subjects with autism. *Encephale*, 34, 550-556.
http://dx.doi.org/10.1016/j.encep.2007.10.010
PMid:19081450

Greenberg, D. L., Keane, M. M., Ryan, L., & Verfaellie, M. (2009). Impaired category fluency in medial temporal lobe amnesia: the role of episodic memory. *Journal of Neuroscience*, 29, 10900-10908.

http://dx.doi.org/10.1523/JNEUROSCI.1202-09.2009

PMid:19726648 PMCid:PMC2761020

Haarmann, H. J., Ashling, G. E., Davelaar, E. J., & Usher, M. (2005). Age-related declines in context maintenance and semantic short-term memory. *The Quarterly Journal of Experimental Psychology. A, Human Experimental Psychology*, 58, 34-53.

http://dx.doi.org/10.1080/02724980443000214

PMid:15881290

Hillier, A., Campbell, H., Keillor, J., Phillips, N., & Beversdorf, D. Q. (2007). Decreased false memory for visually presented shapes and symbols among adults on the autism spectrum. *Journal of Clinical and Experimental Neuropsychology*, 29, 610-616.

http://dx.doi.org/10.1080/13803390600878760

PMid:17691033

Kamio, Y., Robins, D., Kelley, E., Swainson, B., & Fein, D. (2007). Atypical lexical/semantic processing in high-functioning autism spectrum disorders without early language delay. *Journal of Autism and Developmental Disorders,* 37, 1116-1122.

http://dx.doi.org/10.1007/s10803-006-0254-3

PMid:17080275

Kamio, Y. & Toichi, M. (2000). Dual access to semantics in autism: is pictorial access superior to verbal access? *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, 41, 859-867.

http://dx.doi.org/10.1111/1469-7610.00673

PMid:11079428

Kamio, Y. & Toichi, M. (2007). Memory illusion in high-functioning autism and Asperger's disorder. *Journal of Autism and Developmental Disorders,* 37, 867-876.

http://dx.doi.org/10.1007/s10803-006-0214-y

PMid:17031448

McCleery, J. P., Ceponiene, R., Burner, K. M., Townsend, J., Kinnear, M., & Schreibman, L. (2010). Neural correlates of verbal and nonverbal semantic integration in children with autism spectrum disorders. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, 51, 277-286.

http://dx.doi.org/10.1111/j.1469-7610.2009.02157.x

PMid:20025622

Molesworth, C. J., Bowler, D. M., & Hampton, J. A. (2005). The prototype effect in recognition memory: intact in autism? *Journal of Child Psychology and Psychiatry and Allied Disciplines*, 46, 661-672.

doi:JCPP383 [pii];10.1111/j.1469-7610.2004.00383.x [doi].

Retrieved from PM:15877770

Newschaffer, C. J., Croen, L. A., Daniels, J., Giarelli, E., Grether, J. K., Levy, S. E. et al. (2007). The Epidemiology of Autism Spectrum Disorders. *Annual Review of Public Health*, 28, 235-258.

doi: 10.1146/annurev.publhealth.28.021406.144007.

http://dx.doi.org/10.1146/annurev.publhealth.28.021406.144007.

Nissan, J., Abrahams, S., & Della Sala, S., (2013). Amnesiacs might get the gist: reduced false recognition in amnesia may be the result of impaired item-specific memory. *Neurocase,* 19, 478-88.

doi: 10.1080/13554794.2012.701637.

Peña, E. D. (2007). Lost in translation: methodological considerations in cross-cultural research. *Child Development*, 78, 1255-1264.

doi:CDEV1064 [pii];10.1111/j.1467-8624.2007.01064.x [doi].

PM:17650137

Rivière, A. 2004. *IDEA: Inventario De Espectro Autista*. Buenos Aires: Fundec.

Robinson, K. J. & Roediger III, H. L. (1997). Associative Processes in False Recall and False Recognition. *Psychological Science*, 8, 231-237.

http://dx.doi.org/10.1111/j.1467-9280.1997.tb00417.x

Roediger, H. L. & McDermott, K. B. (1995). Creating False Memories: Remembering Words Not Presented in Lists. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 21, 803-814.

http://dx.doi.org/10.1037/0278-7393.21.4.803

Roediger, H. L., McDermott, K. B., & Robinson, K. J. (1998). The role of associative processes in creating false memories. In M.A. Conway, S. E. Gathercole, & C. Cornoldi (Eds.), *Theories of memory* (First ed., pp. 187-239). East Sussex, UK: Psychology Press.

Schacter, D. L., Israel, L., & Racine, C. (1999). Suppressing False Recognition in Younger and Older Adults: The Distinctiveness Heuristic. *Journal of Memory and Language*, 40, 1-24.

http://dx.doi.org/10.1006/jmla.1998.2611

Toichi, M. & Kamio, Y. (2003). Long-term memory in high-functioning autism: controversy on episodic memory in autism reconsidered. *Journal of Autism and Developmental Disorders,* 33, 151-161.

http://dx.doi.org/10.1023/A:1022935325843

PMid:12757354

Williams, D. L., Goldstein, G., & Minshew, N. J. (2006). The profile of memory function in children with autism. *Neuropsychology*, 20, 21-29.

http://dx.doi.org/10.1037/0894-4105.20.1.21

PMid:16460219 PMCid:PMC1847594

Table 1. Descriptive statistics and outcomes from *t*-tests contrasting Comparison participants (CP) and ASD individuals across the three response variables.

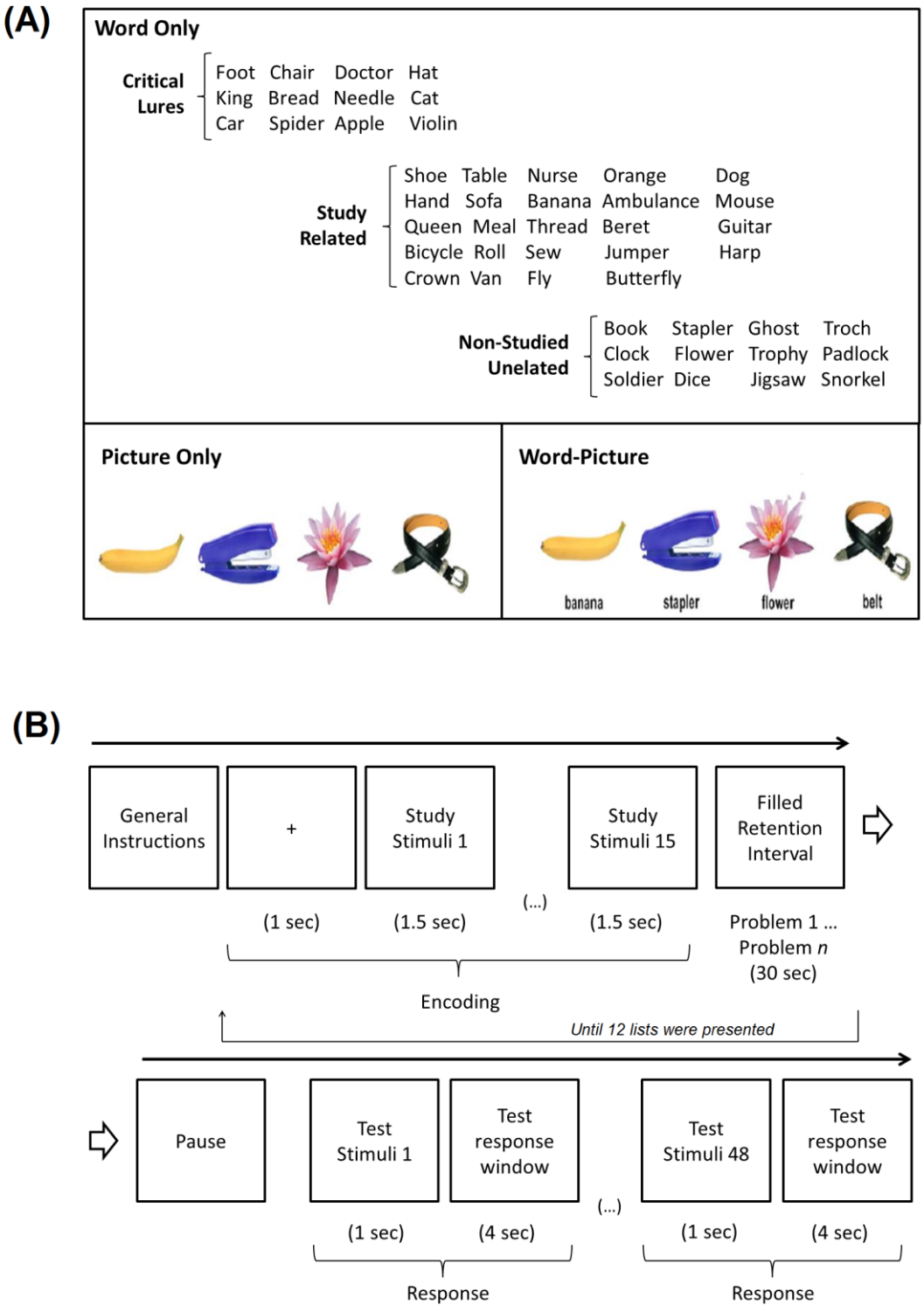
Condition	Variables	Group	Mean	SD	SE	*t*	*p*	Cohen-*d*	*r*
Words	Hits	CP	71.7	13.7	3.5	1.83	0.078	0.57	0.27
		ASD	61.2	17.6	4.6				
	FA	CP	24.4	16.5	4.3	-2.01	0.054	0.66	0.31
		ASD	41.5	28.4	7.3				
	FR	CP	65.6	18.6	4.8	2.45	0.021	0.75	0.35
		ASD	47.1	22.5	5.8				
Pictures	Hits	CP	80.6	10.9	2.8	0.51	0.612	0.17	0.08
		ASD	77.9	17.5	4.5				
	FA	CP	9.9	15.2	3.9	-2.95	0.006	0.96	0.43
		ASD	32.3	25.2	6.5				
	FR	CP	24.9	15.2	3.9	-3.14	0.004	0.98	0.44
		ASD	45.4	20.2	5.2				
Words-Pictures	Hits	CP	77.3	12.0	3.1	-0.13	0.897	0.04	0.02
		ASD	77.9	13.2	3.4				
	FA	CP	13.3	17.6	4.5	-0.19	0.853	0.06	0.03
		ASD	14.6	21.3	5.5				
	FR	CP	27.2	16.6	4.3	-1.24	0.226	0.40	0.20
		ASD	37.8	28.7	7.4				

Hits = "yes" responses to previously studied items; FA = "yes" responses to previously non-studied unrelated items; FR = "yes" responses to previously non-studied related items

Figure captions

Figure 1. (A) Example of the stimuli used in the three conditions of the adapted DRM semantic priming paradigm (see also Supplementary Table 1 for the original list of items used). **(B)** Example of the trial sequence of the task use in this study.

Figure 1


(A)
Word Only
Critical Lures
Foot Chair Doctor Hat
King Bread Needle Cat
Car Spider Apple Violin
Study Related
Shoe Table Nurse Orange Dog
Hand Sofa Banana Ambulance Mouse
Queen Meal Thread Beret Guitar
Bicycle Roll Sew Jumper Harp
Crown Van Fly Butterfly
Non-Studied Unelated
Book Stapler Ghost Troch
Clock Flower Trophy Padlock
Soldier Dice Jigsaw Snorkel
Picture Only
Word-Picture
banana
stapler
flower
belt
(B)
General Instructions
+
Study Stimuli 1
(...)
Study Stimuli 15
Filled Retention Interval
(1 sec)
(1.5 sec)
(1.5 sec)
Problem 1 ... Problem n (30 sec)
Encoding
Until 12 lists were presented
Pause
Test Stimuli 1
Test response window
(...)
Test Stimuli 48
Test response window
(1 sec)
(4 sec)
(1 sec)
(4 sec)
Response
Response

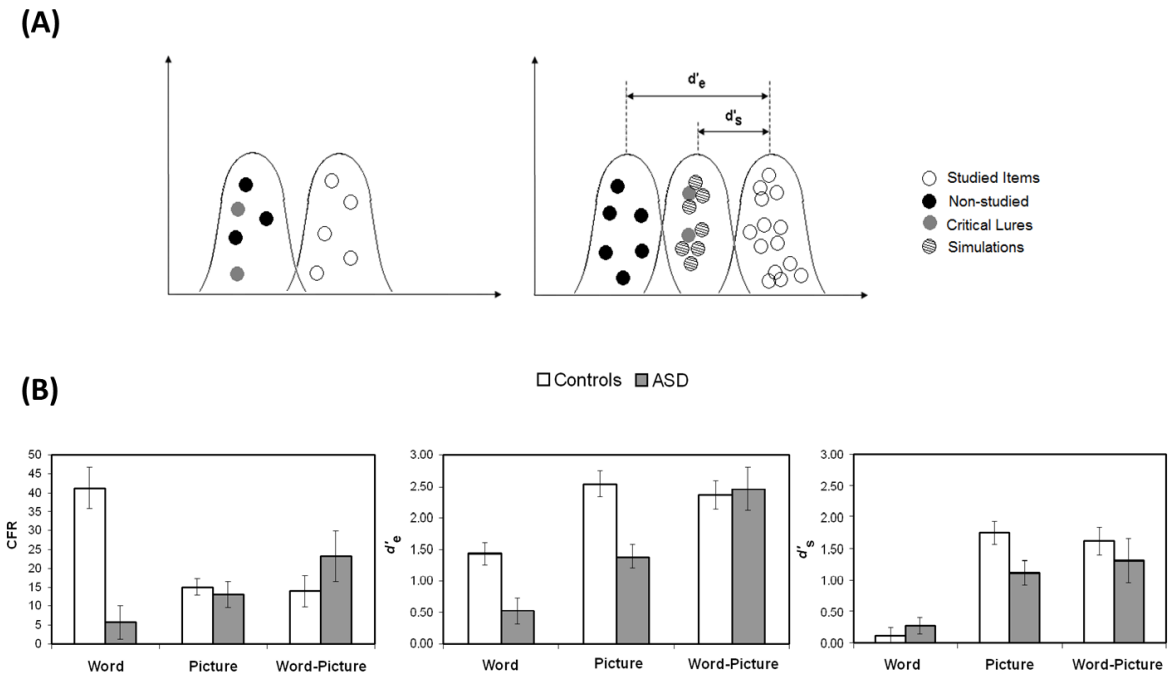
Supplementary Material

Supplementary Table 1. Lists of words (items) used in the task adapted for the present study.

Critical	médico	aguja	pie	araña	violin	silla	sombrero	carro	gato	manzana	pan	rey
Studied words	tijeras	telas	cuerpo	insecto	banjo	mecedora	pantalón	bicicleta	gacela	piña fruta	trigo	castillo
	bisturí	brújula	cuello	libélula	platillos	lámpara	saco	bus	ratón	higo	torta	trono
	enfermero	lana	bota	mariposa	tambor	televisor	gorro	tren	hámster	uvas	jamón	bandera
	portero	dedal	oreja	cucaracha	laúd	cajones	corbata	locomotora	guepardo	lima	vino	príncipe
	cabestrillo	dobladillo	medias	tijereta	arpa	escritorio	guante	motocicleta	perro	grosella	croasan	león
	venda	coser	sandalia	oruga	maracas	estufa	camiseta	moto	tigre	mora	sanduche	espada
	camilla	pinchar	mano	avispa	piano	teléfono	traje	coche	curi	kiwi	agua	bosque
	jeringa	hilo	rodilla	polilla	mandolina	banco	camisa	helicóptero	hiena	melocotón	miel	cetro
	cura	botón	codo	abeja	fagot	armario	falda	furgoneta	ciervo	frambuesa	queso	princesa
	ambulancia	bordar	uña	ciempiés	flauta	taburete	bufanda	barcaza	pájaro	naranja	huevo	mago
	anatomía	cactus	dedo	grillo	trombón	cama	chaqueta	yate	pantera	limón	lechuga	corona
	cirujano	ojal	pierna	babosa	trompeta	sofá	vestido	barco	leopardo	fresa	tomate	caballero
	pastilla	alfileres	zapato	escorpión	clarinete	cojín	boina	avión	lobo	pera	harina	reina
	enfermera	máquina de coser	balón	escarabajo	oboe	mesa	bolso	autobús	rata	melón	comida	estrella
	estetoscopio	cremallera	tobillo	caracol	guitarra	biblioteca	correa	camión	conejo	banano	mantequilla	dragón

Recognition list					
	zapato	libro	naranja	**araña**	Studied
	sombrero	flor	rompecabezas	esnórkel	Non-studied
	coser	corona	**rey**	despertador	Critical
	bicicleta	**pan**	mano	**manaza**	
	guitarra	saco	**carro**	enfermera	
	arpa	ambulancia	candado	mariposa	
	insecto	banano	comida	mesa	
	gato	**médico**	**silla**	trofeo	
	soldado	**pie**	sanduche	dado	
	boina	linterna	fantasma	**violín**	
	perro	hilo	**aguja**	reina	
	cosedora	furgoneta	ratón	sofá	

Supplementary Figure 2. (A) Hypotheses and predictions: representation of the distribution of studied items, non-studied, and critical lures. Poor episodic memory in ASD individuals would not allow the retention of enough items (left panel). Studied and non-studied items would be loosely kept in memory and any semantic link between them would be missed. As episodic memory increases (e.g., with Word-Pictures pairs) more information is accumulated (right panel), the semantic link between studied items is realised leading to a clearer distinction of non-studied items, and activations of the simulations that lead to false recognition. **(B)** Results from ANOVA analyses with CFR (Group vs. Condition) and *d'* (Group vs. Condition vs. Memory [Episodic: d'_e = Z(Hits) – Z(FAs) and Semantic: d'_s = Z(Hits) – Z(FR)]). The results support the hypotheses. Improvement of episodic memory (d'_e) with Word-Picture pairs leads to both better semantic memory (d'_s) and increase of FR (see text in main manuscript for the discussion of these results).



Episodic and semantic memory processes co-occur in the DRM paradigm (see for example Cann et al., 2011). The gist extraction (*d'*$_s$) appears to be contingent on the formation of associative representations (*d'*$_e$) of the to-be-remembered items, thus suggesting that these two processes support each other but operate in parallel. Targets and unrelated lures would be kept in memory relying on surface representations whose distance (*d'e*), would indicate the strength of episodic memory (Supp Fig 2.A). Targets and critical lures however, could be kept in memory relying on semantic representations (*d'*$_s$). However, for the latter to occur, enough information needs to be retained and this would be possible if the episodic memory functions are preserved (Supp Fig 2.A left panel).